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PRELIMINARY STUDIES OF EXERCISE CAPACITY IN COMBAT SWIMMERS AFTER COLD WATER TRAINING OPERATIONS

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Four special warfare combat swimmers performed exercise before and after open water training exercises in swimmer delivery vehicles. The divers wore standard issue dry suits. The water temperature was 7-9 °C. The resting heart rate values were higher in the predive state than in the postdive state. Maximum predive heart rates during a 5 min step test approached 70-90% of the maximum heart rate predicted for age. These high heart rate values were 10-20% higher than values obtained when the exercise was conducted on a nondive day wearing usual exercise gear. Recovery of heart rate after exercise was faster in the postdive state and may be attributed in part to after-drop in rectal temperature. Maximum forearm grip strength decreased approximately 10% in the postdive state. The fatigue rate of the forearm muscles was nearly the same in predive and postdive testing conditions.

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INTRODUCTION

Biomedical needs of operational fleet diving are met in part through research projects conducted in controlled environments. Results obtained in such environments can be applied to many diving situations. The principle of specificity implies, however, that some biomedical responses to diving are best studied under the conditions that prevail operationally. This report presents a preliminary biomedical study conducted with divers during actual open water exercises.

The study was conducted with combat swimmers. These special warfare divers represent a subset of the fleet diving community with some peculiar work requirements. For example, a swimmer delivery vehicle (SDV) operator must at times remain fairly inactive in cold water during transit and then perform a variety of work tasks. After completing the exercises, the SDV operator again becomes relatively inactive for the return trip.

The objective of this study was to examine measures of endurance and strength in SDV divers after cold water exposures. An exercise step test was administered both before and after the operational dive to assess aerobic capacity. A handgrip dynamometer test evaluated forearm strength.

METHODS

Four SDV divers signed informed consent documents. The physical characteristics and diving conditions are provided in Table 1. Dives were conducted as part of routine SDV training evolutions with two SDV divers manning the vehicle during each dive. Heart rate (HR) was measured with three electrocardiogram (ECG) leads attached to a portable monitor (414 monitor, Spacelabs, Hillsboro, OR). Core temperature was estimated by insertion of a thermistor 10 cm into the rectum. Temperature was displayed

TABLE 1

Subject Parameters and Dive Conditions

Subject Parameters			Dive Conditions*			
Age (yr)	Height (cm)	Weight (kg)	Air Temp. (°C)	Water Temp. (°C)	Dive Duration (min)	Depth (fsw)
27 ± 3	184 ± 9	86 ± 12	14.8 ± 0.3	8.2 ± 0.3	99 ± 33	20 ± 5

* n = 3 dive days.
Values are mean ± SD.

digitally on the portable monitor. After predive recordings were obtained the ECG and thermistor leads were secured to the diver's insulation garment.

The exercise step test was done at the dockside; the diver stepped up and down on a 32 cm step at a rate of 30 steps/min for 5 min. This level of exertion would require an energy expenditure of about 9.6 METS (1 MET = resting oxygen consumption). This is equivalent to an oxygen consumption of 32-38 ml/kg/min or to running at 11 min/mile (American College of Sports Medicine, 1980). For the highly fit combat swimmer this was expected to be about 60-70% of maximum aerobic capacity. Before the step test the diver sat on the step for 5 min while resting heart rate was obtained. After the step test the diver again sat on the step for an additional 5 min while recovery of heart rate after exercise was monitored.

The exercise test was performed once on the nondive day with the divers wearing ordinary exercise gear. On dive days the test was performed with the divers wearing their passive thermal protection dry suit (CF200-D, DUI Inc., San Diego, CA) and its m-400 Thinsulate® undergarment. During testing, the dry suits were partially unzipped to allow attachment of the ECG and thermistor leads to the patient monitor.

To test forearm muscle strength, the subject gripped a handgrip dynamometer. This test was performed while the subject was seated with his elbow flexed 90°. Initially, three trials of maximum handgrip strength were done with the right hand, the dominant hand of each subject.
One minute elapsed between each maximal grip.

The rate of forearm muscle fatigue was evaluated by setting the dynamometer to 80% of the maximum grip strength. The subject then attempted to maintain this level of force for 90 s. Dynamometer readings were taken every 5 s.

Before dressing for the dive all subjects urinated and then wore a urine collection device beneath their dive garments. Urine production during the dive was measured volumetrically as soon as possible in the postdive state.

To determine if fluid loading before the dive affected urine production and exercise capacity, one diver of each SDV pair drank 950 ml of a carbohydrate/electrolyte fluid (Gatorade) immediately before entering the water.

RESULTS

Urine production was somewhat greater in the individuals who drank the predive fluid (265 ± 128 ml) compared to those who did not drink any fluid (197 ± 53 ml), but the difference was not statistically significant. Predive fluid loading had no apparent effect on either exercise capacity or muscle strength. It should be borne in mind, however, that this is a relatively small sample population with a relatively short dive duration.

Table 2 summarizes heart rate data obtained from six step tests the four divers performed. Pre-exercise resting HR on a dive day was significantly higher than the corresponding value on the nondive day. This higher value can not easily be ascribed to a thermal effect of wearing the dive garment because rectal temperature was within normal bounds (37.7 ± 0.3 °C). Normal predive apprehension likely provided an appreciable contribution to this elevated resting heart rate.

Postdive resting HR was significantly lower than the corresponding predive value in five of six trials. In the sixth trial a marked elevation in postdive HR (from a predive rate of 68 beats/min to a postdive rate of 86 beats/min) occurred probably because the subject was distraught over technical errors committed during the training dive. Pre-exercise rectal temperatures

TABLE 2

Heart Rate Values*

	Nondive Day	Predive	Postdive
Pre-exercise rest	65 ± 3	80 ± 9†	73 ± 10‡
5th min of exercise	141 ± 8	169 ± 14†	160 ± 9‡
5th min postexercise	74 ± 7	107 ± 8†	86 ± 11‡

* Beats/min.
† $p < 0.05$ from nondive day.
‡ $p < 0.05$ from predive value.
Values are mean ± SD.

were nearly the same in the postdive and predive states. It is likely that the lower postdive resting HR values were influenced in part by the removal of psychological apprehension.

Maximum HR values obtained during the 5 min step test were significantly higher during the predive test. The fifth minute values presented in Table 2 represent 87 ± 7% of the predicted age related maximum heart rate. On the other hand, values obtained during exercise on the nondive day were 73 ± 5% of the predicted maximum. The large exertional HR obtained on a dive day undoubtedly reflects both added energy costs imposed by suit resistance and effect of temperature increases within the suit.

Interestingly, maximum exertional heart rates obtained in the postdive state were significantly lower than predive HR. Further on in this report we present evidence to indicate that the lower postdive maximum HR may be causally related to slight decreases in rectal temperature.

In the postdive period HR values obtained 5 min after exercise were notably lower than predive values. This may be related to a slightly lower core temperature as well as the absence of apprehension. Overall HR responses to exercise are illustrated graphically in Fig. 1. Compared to the control curve obtained on a nondive day both predive and postdive curves reflect the greater amount of work required in doing a step test in the dry suit. Nervous influences that raised HR may also account for some of the upward displacement of the predive curve.

Core temperature was reasonably well maintained throughout these short duration dives. Only one subject exhibited a decrease in resting postdive rectal temperature (from 38.1 to 37.2 °C). On the average, resting postdive rectal temperature was 37.8 ± 0.4 °C.

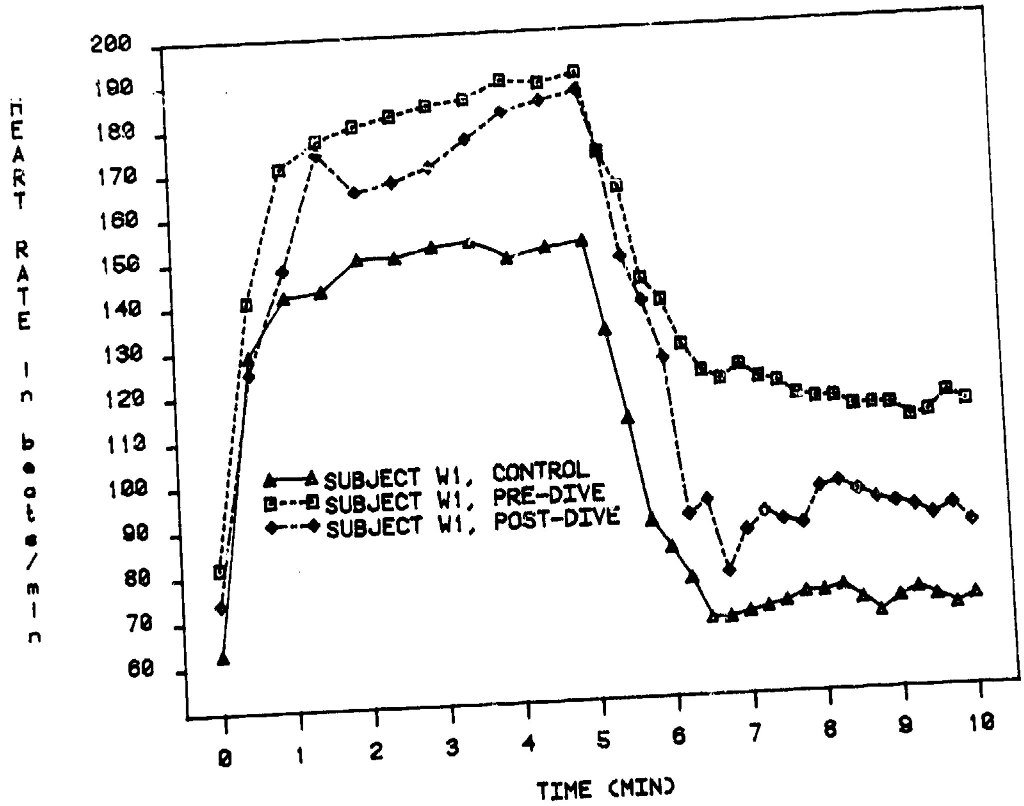

Fig. 1. Heart rate values for one subject on nondive day (control) and dive day (predive and postdive). Values at time 0 are resting heart rates. Step test exercise occurred from 0-5 min and postexercise phase from 5-10 min.

During the predive exercise test rectal temperature increased within a range of 0.1-0.3 °C. By way of contrast, postdive exercise resulted in decreases in rectal temperature ranging from 0.1-1.8 °C. The exercise induced after-drop in rectal temperature in the postdive period occurred in all subjects, probably as a result of cool peripheral blood returning to the core. The response of one subject is presented in Fig. 2. This subject had a postdive decrease in rectal temperature of 0.9 °C and a further drop of 0.3 °C within the first 2 min of exercise. The subject with the largest after-drop experienced a 1.8 °C decline within the first 4 min of exercise.

Maximum handgrip force decreased by 10% after completing the cold water training exercise. Predive maximum values were 69 ± 3 kg and postdive measurements were 62 ± 8 kg ($p < 0.05$).

The rate of forearm muscle fatigue for one subject tested by attempting to maintain 80% of maximum force for 90 s is shown in Fig. 3. In the predive state the initial decline in force over the first 30 s was much faster than in the postdive test. At the end of 90 s force values were nearly the same for predive and postdive periods. Force values obtained at 90 s for six trials averaged 29 ± 3 kg predive and 29 ± 5 kg postdive.

While postdive maximum handgrip strength was less than predive strength, the 90 s fatigue endpoints were the same. Thus, the overall rate of fatigue was slower after cold water exposure. Force in the first 30 s of the force-time curve was governed predominantly by fast twitch muscle fiber activity (Simon, 1983). Therefore, predive and postdive differences in this region may reflect a faster rate of fatigue of the fast twitch fibers after cold water exposure.

The latter segment of the force-time curve (30-90 s) was controlled by the rate of fatigue of the slow twitch fibers (Simon, 1983). The similarity

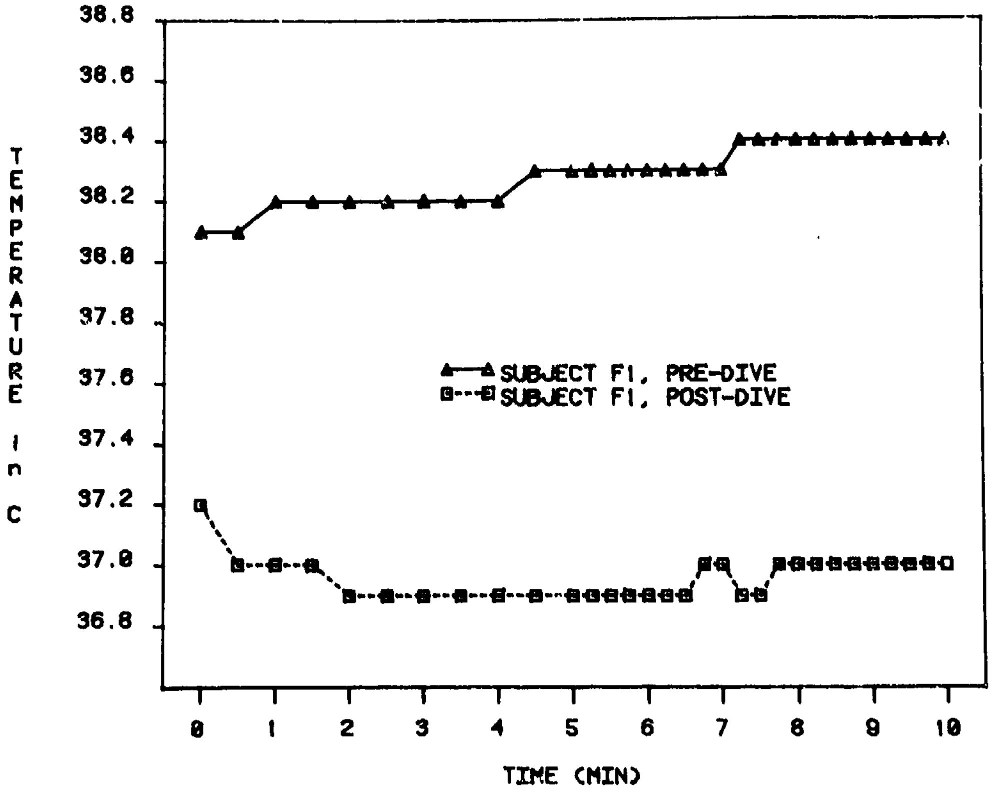

Fig. 2. Rectal temperature obtained in one subject before and after 135 min in 8 °C water. Exercise step test occurred from 0-5 min and postexercise period from 5-10 min.

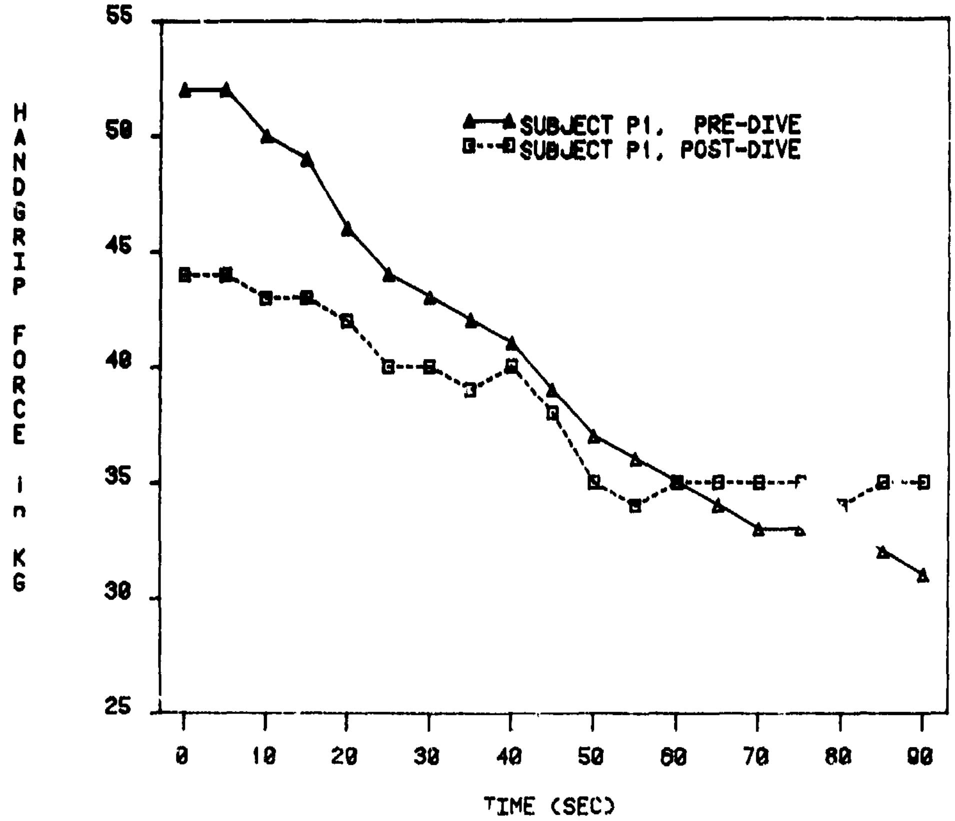

Fig. 3. Handgrip force in one subject exerted over 90 s. Time 0 data point represents 80% of maximum grip strength (65 kg for predive and 54 kg for postdive).

between predive and postdive values in this segment of the curve suggests little change in the rate of slow twitch fiber fatigue.

DISCUSSION

This preliminary study measured exercise capacity in divers under actual open water diving conditions. It demonstrated that open water research testing relevant to fleet diving concerns can be conducted with minimal alterations of the dive plan.

Changes were detected in exercise capacity that may directly affect diving missions. Although the passive diver thermal protection garment is capable of minimizing body heat loss in cold water, we were able to document temperature related decreases in aerobic power and skeletal muscle force after open water missions. Obviously, additional studies are required to quantify the extent of these changes and to what degree they might alter operational missions.

Consumption of 1 L of fluid before the dive produced no detectable changes in step test performance, rectal temperature, or handgrip strength. The small number of subjects precludes any definitive statement, however. Relationships of immersion time and temperature to exercise capacity and fluid loading require further study.

The heart rate data obtained during the exercise step test provided some interesting clues to the nature of operational diving stresses. Higher resting HR in the predive state no doubt reflects some predive anxiety. This notion was supported by the lower resting HR values observed after the dive was completed and on the nondiving day. This finding is being explored in a larger series of subjects to quantify noninvasively underlying changes in basal nervous system tone.

The high heart rates achieved during the step test conducted wearing the dry suit could be attributed to both the resistance of the suit and to temperature rises within the suit. Although rectal temperature increased only slightly during the predive exercise, sweating was evident in all subjects, suggesting a temperature build up due to lack of usual avenues for heat loss. Sweating was subjectively absent or reduced during the postdive test.

Differences in exercise HR values before and after the dive provided some insight as to the relative contributions of temperature and suit resistance to the observed changes in heart rate. The cold water nature of the dive supports the assumption that the body shell was likely cooler in the postdive state. Heat generated by exercise in the postdive period would be distributed to a cooler shell, thereby buffering any rise in core temperature. Consequently, HR would be little affected by muscle heat production. The difference between predive and postdive curves (Fig. 2.) approximates the effects of temperature and anxiety on heart rate. By similar reasoning, the difference between the nondive control curve and the postdive curve estimates the HR response due to the physical resistance of the suit.

Postdive heart rate responses to exercise in a sense mimic what the combat swimmer might encounter operationally. In this study, the diver spent an average of 99 min relatively inactive within the SDV. He then performed a 5 min aerobic test on land. Under normal circumstances (nondiving) this effort would be about 60-70% of his maximum aerobic power. Under dive conditions, however, the higher exercise HR predicts that the same work effort now approximates 80-90% of maximum aerobic power. Consequently, even in a very fit individual endurance time would decrease. It is in this area that additional testing would be extremely valuable to determine the operational extent of exercise capacity.

The faster HR recovery after exercise in the postdive state might appear beneficial. If heart rate recovery is associated with after-drops in rectal temperature, however, then this association could portend a more insidious consequence. For example, if an individual's core temperature dropped to 35-36 °C, then the exercise induced after-drop in temperature to 30-34 °C could precipitate serious cardiac arrhythmias (Paton, 1983). This consideration needs careful attention when planning working dives in cold water.

Decreases in maximum handgrip strength after a dive agree with findings obtained in controlled laboratory settings (Coppin, Livingstone, and Kuehn, 1978; Johnson and Leider, 1977). Maximum force depends upon velocity of contraction, particularly of the fast twitch muscle fibers (Simon, 1983). Cooling is known to reduce the rate of contraction of this fiber type. Consequently, the initial segment of the handgrip force-time curve is depressed in the postdive condition due partly to suppression of fast twitch fiber activity.

The latter part of the handgrip curve is governed primarily by slow twitch muscle fibers. A lower temperature in the forearm muscles would prolong the duration of the active contractile state for individual fibers. Consequently, submaximal force could be maintained for longer periods, and the postdive rate of fatigue would appear to be similar to that in the predive test. Mechanistically, however, the two situations may be different.

Operationally, the results of the handgrip test indicate that rapid movement, as well as maximum force, would diminish after cold water dives. The ability to maintain submaximal forces would, however, be functionally unaltered under these conditions.

The results of this preliminary study can offer general guidelines for operational use. Further testing is necessary with a greater number of subjects, particularly in work specific areas, before explicit guidelines can be offered. It appears that sustained exercise in the passive diver thermal protection garment should be minimized, particularly on land where suit resistance and thermal constraints are pronounced. Any added constraint increases the effort required for a given workload, thereby reducing endurance time. Supervisors of SDV operations should be particularly cautious when their divers are required to exercise after long duration cold water diving. In this situation, the after-drop in rectal temperature may become hazardous. The last general point concerns physical fitness training. If combat swimmer operations require sustained exercise, every effort should be made to ensure that the divers are trained to their maximum aerobic capacity before the dive. Further, the training should be as task specific as possible to enhance work capacity. Individuals not trained to their maximum aerobic capacity will exhibit proportionally higher heart rates and proportionally shorter endurance times.

Cooling of forearm muscles reduces maximum handgrip force. In this dive series, which averaged about 1.5 h bottom time, maximum force declined about 10%. This depression continued for the first 30 s of sustained isometric contraction. Therefore, it would seem advisable in cold water operations to minimize tasks requiring effort close to 100% of a maximum voluntary contraction. These task specific efforts include not only maximum force, but the speed in which the movement must take place. Submaximal force can apparently be maintained without decrement in the cold water environment. Individuals afforded the opportunity to train forearm muscles might experience less decline in handgrip force during cold water dives.

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